NUCLEAR WEAPON TESTING AND STUDIES RELATED TO HEALTH EFFECTS: AN HISTORICAL SUMMARY

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could penetrate the human environment had aroused deep public concern and anxiety. At issue was not only public faith in government, which was a frequent subject of discussion at the Salt Lake City hearings, but also the basic scientific assumptions about the health hazards of radiation. Decades of research had greatly enlarged scientists' understanding of the mechanisms of radiation damage, but inherent characteristics of radiation and its effects made it all but impossible to prove that low levels of radiation actually caused cancer.

Because no disease is uniquely attributable to radiation, scientists must rely on statistical methods to detect its biological effects. By the time of the Salt Lake City hearings scientists had firm evidence that high doses of radiation caused serious forms of cancer, but even the most sophisticated statistical methods still left great uncertainty about the effects of levels of exposure as low as those attributed to fallout from weapon tests. Statistics, however, were cold and impersonal indicators of human suffering and tragedy. In Salt Lake City Senator Orrin G. Hatch of Utah described his meeting the previous evening with residents of a small town who had suffered from what they were convinced were the ravages wrought by radioactive fallout:

> There are probably no words in our language poignant enough to clearly demonstrate the tragedy, or to measure the pain and the genuine loss suffered by each of the 48 Utahans who came to bear witness to what has been done to them. One woman talked of the photographs she had lying on her bedroom dresser at home. These photographs of the dark 'mushroom cloud' were taken several miles from the blasting site by her husband and only son two decades ago. Since then, this woman watched both her husband and son die of the most painful kind of cancer, a cancer with which she herself is now afflicted. And soon, only the photograph will remain.

On April 19, 1979, four United States Senators, four members of the House of Representatives, two State Governors, and a score of federal and state officials joined members of the public in opening a congressional hearing in Salt Lake City on the "health effects of low-level radiation." Although the subject sounded somewhat technical and esoteric, the presence of so many distinguished government officials suggested that the occasion was more than a routine investigation. Indeed, from the outset the speakers made clear that they were concerned about issues of life and death, about the very nature of human existence in the modern world, and the ability of government to assure public health and safety within the democratic system.

The question before the Salt Lake City hearing was whether ionizing radiation from nuclear weapon tests conducted by the federal government had been responsible for causing cancer in persons living in the three-state area near the test site. Since 1951 the United States Atomic Energy Commission and its successor agencies had announced the detonation of 539 nuclear weapon devices at the Nevada test site northwest of Las Vegas. One hundred thirty-nine of these tests had released measurable amounts of radiation beyond the boundaries of the site. Although most of this radioactivity had been deposited as fallout in Utah, Nevada, and New Mexico, enough had fallen in other parts of the nation and across the northern hemisphere to cause public concern about its effects on the health of humans and the environment.

Despite assurances by the Atomic Energy Commission and other federal agencies that the nuclear tests had posed no significant health hazard to the public, the mounting evidence of the multiple pathways by which radiation

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was lighted by a searing light with the intensity many times that of the midday sun. It was golden, purple, violet, gray and blue. It lighted every peak, crevass and ridge of the nearby mountain range with a clarity and beauty that cannot be described....Thirty seconds after the explosion came, first the air blast pressing hard against people and things, to be followed almost immediately by the strong, sustained awesome roar which warned of doomsday...." It was 5:29 on the morning of July 16, 1945, at Alamogordo. The world had entered the nuclear age.

Although the extraordinary lighting effects were the most impressive aspect of the world's first atomic detonation for the observers at the base camp ten miles from ground zero, there were other phenomena associated with the test that were of greater concern to scientists. For weeks some of them at the Los Alamos laboratory had been devising ingenious methods of measuring the physical effects of the explosion during the first few thousandths of a second after the critical mass was formed. In addition to gauging blast effects it was important to observe details of the fission process as it evolved by determining the intensity and duration of the burst of neutrons and gamma rays produced in the reaction. The delicate instruments had to be carefully shielded so that they could function close enough to ground zero to be effective without being destroyed by the blast or saturated by subsequent radiation. Immediately after the shot, technicians with radiation instruments began to take readings on the test site and gradually moved forward toward ground zero wherever low radiation readings permitted. Within a few weeks it was possible to obtain radioactive samples of materials fused by the tremendous heat into a glass-like substance within the crater itself.

If, as Senator Edward M. Kennedy charged at the hearing, the federal government had inflicted this kind of danger on its citizens "without their consent, without their knowledge, and without taking proper precautions," then any appraisal of the government's role in nuclear weapon testing involves not only questions of competence and prudence but also moral issues of truth, integrity, and human compassion.

The following pages do not presume to answer these questions or even to present all the facts needed to resolve them. Rather the purpose is to set the evolution of events in their historical context so that we may better understand how these things came to be.

DAWN OF THE NUCLEAR AGE

The rain had stopped two hours before dawn and there was almost no air stirring. As the first glimmer of light appeared on the eastern horizon, the anxious voice of Sam Allison, a chemistry professor at the University of Chicago, echoed over the public-address system in the lonely reaches of the New Mexican desert. Tension mounted as the countdown proceeded. During the final few minutes, scores of scientists, engineers, military personnel, and a few high-ranking government officials from Washington assumed prone positions on the ground with their eyes covered. When Allison finally cried "Now!" the prostrate witnesses were engulfed by a fierce light that momentarily blinded them despite their covered eyes. One Army veteran, a brigadier general, later wrote that the experience was "unprecedented, magnificent, beautiful, stupendous and terrifying." "No man-made phenomenon of such tremendous power," the general wrote, "had ever occurred before. The lighting effects were beyond description. The whole country

obtained at points several miles beyond the eastern stations. The results confirmed that radioactive fallout could be a significant danger from nuclear detonations and showed that fallout was not uniform even directly under the path of the cloud.

Three weeks after Alamogordo, units of the United States Army Air Force dropped two atomic bombs on Japan. Although of different types, the two bombs had similar yields and were detonated at similar heights--12.5 kilotons of TNT at 1,893 feet at Hiroshima and 22.0 kilotons at 1,663 feet at Nagasaki. The weapons virtually destroyed the two cities, killing 68,000 civilians and injuring 76,000 at Hiroshima and killing 38,000 and injuring 21,000 at Nagasaki. The characteristics and magnitude of destruction from blast and thermal radiation were unprecedented for a single weapon, but in some ways were comparable to the results of fire-bombings with conventional weapons earlier in World War II. Unique at Hiroshima and Nagasaki were the effects of nuclear radiation. Horrible as these disasters were, medical scientists after the war did have what was hoped would be the only opportunities in human history to observe the radiation effects of nuclear weapons on human beings. Five weeks after the attacks American scientists and medical teams arrived at the ruined cities to assure that there was no residual radiation before the American occupation troops arrived. At the same time the survey teams began recording the physical and biological damage. The investigations of biological effects continue to this day under joint Japanese and American leadership.

The fact that both detonations occurred under combat conditions posed unusual problems in determining the biological effects of radiation; it had

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Because the Alamogordo test had occurred deep in the desert far from any centers of human population, there seemed little chance that people outside the test area would be endangered by radiation, except from radioactive particles that might be carried high into the atmosphere by the explosion and transported by the wind to other areas. Those planning the test had foreseen this danger and had made some preparations for it. Six weeks earlier test personnel had detonated one hundred tons of TNT spiked with radioactive materials to test the instrumentation for measuring blast and radiation effects. Weather had become a controlling factor in determining when the shot could be fired. It was essential that prevailing winds not carry the cloud over inhabited areas or that rain cause heavy fallout on personnel in the test area.

To track the cloud produced by the actual test, two Army searchlight units were stationed about ten thousand yards north and west of ground zero to follow the cloud immediately after detonation, while five similar units and a mobile radar set were positioned on a north-south line about twenty miles east of ground zero in the anticipated path of the cloud. Fortunately, the weather forecast proved accurate; the winds held moderate and from the west. By taking bearings on the cloud, the searchlight units were able to plot its location and determine its speed and direction. Ground measurements of radiation at the searchlight stations were taken every five or ten minutes and significant readings were obtained at those stations over which the cloud passed. It was possible to track the cloud visually for more than an hour and monitoring of radioactive fallout continued until noon. The scientists found an expected correlation between radiation levels and the path of the cloud, but some of the highest readings were

bomb had been one of the best kept secrets of the war, with the result that very few people outside the Manhattan Project had any reason to think about the possibility of such a weapon at all. Now the nation (and the world) was suddenly confronted with a completely unexpected and, in some ways, terrifying future. Fortunately, a few officials within the Manhattan Project had been giving some thought for almost a year to the place of atomic weaponry in the post-war period. The enormous power of nuclear weapons suggested the urgent need for effective international controls and domestic regulation. The dangers posed by radiation in nuclear activities seemed to require extensive, if not total, control of peaceful uses of the technology by the federal government. Even before the Alamogordo test, War Department lawyers had drafted legislation that would vest this unprecedented authority in an atomic energy commission.

When the legislation was introduced in Congress in October 1945, Administration leaders and the Army officers who were still in charge of the Manhattan Project hoped that the bill establishing the Atomic Energy Commission would be adopted quickly before the wartime atomic energy project disintegrated. In the autumn of 1945, however, quick action proved impossible. The nation had finally begun to find its bearings in the post-war world. The precipitous demobilization of the nation's armed forces reflected a strong reaction against the military, an emotion that was strengthened by the revelations of military bungling in congressional investigations of the Pearl Harbor disaster.

For the hundreds of scientists and engineers still in the Manhattan Project, the proposed legislation posed special problems. More aware than most people of the potential catastrophe of nuclear warfare, the project

been impossible to have in place even the relatively crude instruments that were used at Alamogordo to measure the dispersal and intensity of nuclear radiation. Efforts to find "natural" dosimeters in the bombed-out areas (such as measuring radiation induced in ceramic insulators on telephone poles) proved unsuccessful, and American scientists were forced to rely on calculations of the nuclear properties of the weapons themselves in determining the nature and intensity of the radiation received on the ground. Even the exact positions of the weapons at the time of detonation were in doubt for many years. The injuries from thermal and nuclear radiation suffered by the thousands of dead, dying, and survivors were all too evident, but correlation of these injuries with the amount of nuclear radiation received was impossible unless the precise location of each individual and the amount of shielding between that person and the bomb could be determined. The American medical and scientific teams on the scene soon realized that, in addition to meeting the immediate medical needs of the survivors, it was vital to organize a long-term research effort that would make it possible to calculate the amount and nature of the radiation received by each of thousands of individuals and then to observe the emerging biological effects in personal case histories over a period of years. Establishment of such a program, however, would have to await the creation in 1946 of a federal agency that could provide financial support. Not until 1967 was there an accurate and complete description of the radiation exposure to individual survivors.

CONTROLLING THE BOMB IN THE POST-WAR WORLD

Never before in history had a new technology been introduced with so little warning and such awesome dimensions. The effort to build the atomic

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personnel saw international control of atomic energy as the first priority. But strong international control implied equally rigorous domestic restrictions, which in turn raised the possibility that the traditional freedoms to conduct research without government interference might be jeopardized. Such fears were strengthened by the Army's attempts to keep the scientists and engineers in the laboratories, and out of political issues in Washington. The same Sam Allison who had announced the countdown at Alamogordo told the press in September 1945 that the scientists might decide to do no more than "study the color of butterfly wings" if the Army insisted upon imposing restrictions on their activities.

The Army's proposed legislation would not necessarily have resulted in the kinds of restrictions that the scientists feared, but it did help to make the question of military control a national issue. Sparked by the Manhattan Project scientists, the demand for civilian control of atomic energy was quickly picked up by both congressional leaders and Administration officials. In attempting to defend its legislative proposal, the War Department used heavy-handed methods that succeeded not only in arousing further opposition among the scientists but also in alienating support in the White House and the Congress. Although the Army bill provided that only two of the nine proposed members of the Atomic Energy Commission would be military officers, President Truman found even that small representation unacceptable and instructed the War Department on November 30, 1945, to insert language excluding military officers from membership on the Commission. With this decision, support for the Army bill collapsed and a completely new bill was drafted by a special Senate committee on atomic energy, with active support from the scientists.

The new bill, which after many revisions became law in August 1946, provided the severe and unprecedented controls over nuclear science and technology that the wartime experience seemed to demand. The five members of the Atomic Energy Commission were given absolute control over all fissionable materials and weapons and over facilities for producing them. Under the law, all technology related to these activities was placed in a special security classification that only the Commission itself could remove. The act gave the Commission authority to produce fissionable materials and weapons, provided that the rates of production were approved annually by the President. Presidential approval was also required for transferring weapons or materials to the military. The same act also directed the Commission to support research and development activities in both public and private institutions in five broad areas, two of which were "utilization of fissionable and radioactive materials for medical, biological, health, or military purposes" and "the protection of health during research and production activities."

Although the Atomic Energy Act of 1946 granted the Commission exceptional authority in many areas, it also left the Commissioners with numerous options. Some military leaders hoped that the Commission would use the President's authority to transfer weapons and materials to the armed services as the basis for placing all production and weapon facilities under military control. The Commission could also have confined scientific research and development to government laboratories operated by government employees or it could have placed most of these activities in the hands of industrial contractors or educational institutions.

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As it turned out, the initial members of the Commission opted for absolute civilian control of production and weapon activities and for a broadly based research and development program. The Manhattan Project laboratories already in existence became great centers of research known as national laboratories. Government owned, but operated by university or industrial contractors, the national laboratories became regional centers that made available to scientists the very large and extremely costly research equipment such as nuclear reactors and high-energy accelerators that few universities could afford alone but that were essential for experiments in the nuclear sciences. Within a few years, many scientists were pleased to discover that the national laboratories, with their access to the generous Federal funding, had begun to set new standards for excellence in research, not just in nuclear technology but also in the physical and biological sciences as well. In addition, the Commission launched an ambitious program to support basic research in the physical and biological sciences in the nation's colleges, universities, and private research institutions.

The Commission's decision to exclude the armed services from any role in the production of fissionable materials and weapons left the agency with full responsibility for these activities. The wartime facilities had been hastily built and were not designed for long-term operation. All of the weapon research, development, and manufacturing had been done at the Los Alamos laboratory, located on an almost inaccessible mesa north of Santa Fe, New Mexico. There was some question whether the site was practical for a permanent laboratory, and the wholesale dispersal of the scientific staff to academic jobs raised the possibility that there would be no adequate

staff to man the laboratory even if it were rebuilt as a permanent facility. After considering several alternatives, the Commission decided to rebuild Los Alamos as a first-rate research and development center and to transfer production and ordnance activities to other locations.

REBUILDING THE NUCLEAR STOCKPILE

Despite the Commission's overwhelming desire to make the new agency a civilian organization and to concentrate on nonmilitary uses of atomic energy in 1947 and 1948, the deplorable state of the nation's vaunted arsenal of nuclear weapons forced the Commission to give weapon development and production a high priority. When the Commissioners briefed President Truman in April 1947, they revealed that the entire stockpile consisted of enough components to assemble only a few bombs of the Nagasaki type. The Hiroshima bomb was already considered too inefficient to be employed in anything but a short-term emergency. The Nagasaki weapon was still more a laboratory apparatus than a production model, and there was some question whether the Commission had enough technicians with the training and knowledge to assemble them. The Commission had no choice but to set aside the development of peaceful uses of atomic energy and to concentrate most of its attention on rebuilding and enlarging production facilities for fissionable material, getting Los Alamos on a firm footing, and developing a new model of the atomic bomb to replace the relatively crude wartime weapons that required extravagant amounts of scarce fissionable materials.

While Los Alamos hurriedly mobilized available manpower and resources to develop new weapon designs, the Commission looked ahead to the need for testing the most promising designs, early in 1948 if possible. After

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considering several sites, the Commission chose the Enewetak Atoll in the central Pacific, just 180 miles west of Bikini, where the military services had detonated two nuclear weapons of the Nagasaki type in the summer of 1946.

The Crossroads test series at Bikini, intended primarily to determine the effects of the bomb on naval vessels and military equipment, did nothing to advance the art of weapon design. The Commission's Sandstone tests at Enewetak in the spring of 1948 were heavily instrumented and provided the data essential for designing improved weapons, which went immediately into production. Neither the Crossroads nor the Sandstone tests, however, provided for well-coordinated measurements that would relate radiation dose to biological effects, although teams of biologists in both instances were permitted to observe the general effects of radiation on plant, animal, and marine life. The Crossroads data were especially valuable because the scientists were invited to survey the atoll before the first test so that comparisons could be drawn with conditions after the tests and at periodic intervals over the next several years.

By the time of the Sandstone test series in 1948, the Atomic Energy Commission had organized a far-reaching program for research in the biomedical sciences. Much of this research was related to studies of cancer and the treatment of cancer with radioisotopes. It had long been known that radiation could cause cancer by ionizing molecules within tissue, but the precise mechanisms were not understood. To avoid duplicating work supported by the American Cancer Society and the U.S. Public Health Service, the Commission focused on research and therapy in which the use of radiation would be particularly useful.

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The Commission also assured the continuation of the long-term study of Hiroshima and Nagasaki victims by helping to establish and to fund completely the Atomic Bomb Casualty Commission, operated in Japan by the National Academy of Sciences under a Commission contract. The initial plan had been to set up research centers in Hiroshima and Nagasaki with smaller centers for control purposes at Kure and Sasebo, but the shortage of supplies, laboratory space, and trained personnel in Japan made this plan difficult to achieve and essentially all of the work was eventually done in Hiroshima and Nagasaki. Despite these difficulties, Japanese and American scientists continued their observations of survivors. In 1949 radiation cataracts began to show up in survivors who were within one thousand meters of ground zero, and in the following years the first leukemia cases appeared among survivors within two thousand meters of the epicenter. For both diseases the incidence among Hiroshima and Nagasaki survivors was clearly higher than in normal urban populations in Japan.

The American physicians directing the work were also looking for long-range effects, both somatic and genetic. One concern was whether exposure to very large amounts of radiation could have unique pathological effects. In the area of genetics, studies were organized to look for radiation-induced mutations in genes that might show up as still births, birth defects, increased infant mortality, and changes in sex ratio. All of these studies required an enormous amount of effort in keeping track of subjects, completing periodic examinations, and obtaining medical reports on those who died. The scientists working in Japan were not surprised that little evidence of radiation-induced diseases or genetic defects appeared within the first few years of the studies. Somatic effects other than cataracts and leukemia might take years to appear and genetic effects, decades to find.

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NUCLEAR WEAPONS AND THE COLD WAR

If no further tests of nuclear weapons had been necessary after 1948, the specter of Hiroshima and Nagasaki might have faded from the public consciousness and the growing anxiety over the dangers of radiation might have been avoided. But the early post-war hopes for a world at peace and atomic energy under international control had already begun to fade. By the end of 1946, the Soviet Union had rejected an American offer to put all atomic energy activities under the control of an international commission within the United Nations. In 1947, President Truman had launched the Marshall plan to prevent the Soviet Union from moving into the political and economic vacuum that persisted in the still war-ravaged nations of the Middle East and Western Europe. By the end of the year, hopes for negotiating a peaceful settlement with the Soviet Union in Europe had disintegrated at the foreign ministers' conference in London, and there were indications that the Soviets were planning more overt aggression in Western Europe. These fears were realized early in 1948, when a communist coup in Czechoslovakia overthrew the last democratic government in Eastern Europe. Late in March, relations between Allied and Soviet representatives in Berlin broke down and the Soviets began to threaten both rail and highway connections between Berlin and West Germany. The outlook was so ominous to American diplomatic and military leaders that the outbreak of war seemed a real possibility. The Commission even considered postponing the Sandstone tests to conserve its meager stockpile of nuclear weapons and to avoid the danger that Soviet forces might attack the American test group at Enewetak and destroy the equipment and technicians necessary to assemble the Nagasaki models of the

bomb. The year 1949 brought the victory of the communist forces of Mao Tse-tung in China and the first detonation of a Soviet atomic weapon in August, five years earlier than many American leaders believed possible.

All of these alarming developments in international affairs inevitably brought new pressures to increase its production of fissionable materials, to develop new types of fission weapons of much smaller size and yield than the large strategic weapons proved out in principle at Sandstone. News of the first Soviet atomic bomb set off within the government an intense and prolonged debate over whether the Commission should accelerate its efforts to develop a thermonuclear weapon that might be a thousand times more powerful than the weapons dropped on Hiroshima and Nagasaki. That debate, which ended in President Truman's decision to proceed, raised animosities within the atomic energy establishment that would fester for a decade.

In the spring of 1950 the Commission was already working on an emergency basis on all fronts--to increase the production of bomb materials; to develop and produce a "family" of fission weapons designed not only for strategic bombing but also for tactical use in missiles, land mines, and howitzers; and to find the secret of the hydrogen bomb. In June, when communist troops launched an attack on South Korea, President Truman responded to the United Nations' call for military action by sending American military and naval forces into the area. Whether this "police action" would lead to full-scale war, no one could predict. If the war should escalate, nuclear weapons might become a decisive factor.

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The rapidly accelerating and expanding efforts to develop new kinds of nuclear weapons imposed a corresponding increase in capabilities for testing. As testing techniques and weapon designs became more sophisticated, it became possible to plan tests that would diagnose specific design problems rather than simply proof-test completed weapons. These diagnostic experiments could be most efficiently performed if Los Alamos had a nearby site where tests could be conducted at various stages of weapon design. The enormous distance between Enewetak and Los Alamos and the attendant problems of communication and transportation made it impossible to perform in the Pacific a succession of diagnostic experiments in a single test series, but such a strategy would be feasible at a continental site. Almost as important would be the substantial savings in manpower and equipment.

The Commissioners had considered the advantages of a continental site in 1947 and again in 1949, when the logistic problems involved in the Sandstone tests became fully apparent, but the idea was set aside as something to be considered only in time of war or national emergency. The Korean War had now removed that condition. The military services were concerned that a full-scale war might cut off Enewetak as a testing area, and there were growing demands in the autumn of 1950 for a continental site where testing could begin early in 1951.

Of the five sites considered, the Las Vegas bombing and gunnery range in Nevada seemed superior. The Nevada site was conveniently close to Los Alamos; it was already under federal control and could be available in a matter of weeks; it was in an area of reasonably predictable weather and wind conditions; and it had the advantage of low population density both near the site and in a wide area in which some fallout could occur

without endangering large populations. Test personnel at Los Alamos assured the Commissioners that, with special precautions, including the firing of tests only under the best weather conditions, radiation hazards to the general public would be minimized. Of all these factors, speed may have been the most important in the selection. Less than two months after the Commission approved the site the first shot was fired.

Although operational requirements for weapon development were clearly paramount in planning and conducting the shots, the test group did take what it considered reasonable precautions to protect the general public from personal injury or property loss. The three principal hazards were sonic blasts that could break windows or damage buildings; the high-intensity light from the detonation, which might cause eye damage; and nuclear radiation, which could cause acute physical injury and possibly long-term somatic and genetic damage. The first two hazards involved relatively well-established physical phenomena and measures to prevent these accidents were easily devised.

The hazards of nuclear radiation, however, were still relatively undetermined, especially in the context of the enormous amounts of radiation that were produced in nuclear detonations. Every weapon test since Alamogordo had revealed some information about the radiation produced. Much less understood were the effects of that radiation on humans and the mechanisms of damage. Because the Pacific tests to date had not involved hazards to off-site populations, precise information about radiation effects was of less concern than obtaining weapon data. Continental tests, however, even in the remote areas of the Nevada desert, posed an unprecedented threat to public safety.

ORIGINS OF RADIATION STANDARDS

Although the amount of radiation that the Commission had to control in 1950 was unprecedented, there was substantial literature and practice in radiation protection on which it could draw. The dangers of radiation had been observed soon after the discovery of ionizing radiation itself late in the nineteenth century. As the uses of radiation, mostly for medical purposes, increased in the twentieth century, physicians and radiologists had organized internationally to draft standards for acceptable use.

These standards were devised empirically. The first attempt to define a tolerance dose in terms of a numerical value was based on exposure patterns in several well-managed installations in which it was possible to estimate the amount of exposure for radiation workers. It was estimated that in the course of a month the workers received one one-hundredth of the amount of radiation that would produce any visible effect on the skin. For practical purposes this amount of radiation was considered harmless at this rate of exposure. A group of radiotherapists later agreed to equate this amount of radiation to a physical unit of measure defined in terms of the ionizing effect of X-rays, the roentgen (R). Under these conditions the tolerance dose worked out as one one-hundredth of a skin unit dose or 6.0R per month.

By the early 1930's the Advisory Committee on X-ray and Radiation Protection in the United States had approved a tolerance dose of 0.1R per day, while the International X-ray and Radiation Protection Committee had adopted a tolerance dose of 0.1R per day. In the absence of further data supporting a more restrictive standard, the Manhattan Project used the 0.1 figure for its operations during World War II, with the provision that this

was an upper, not a recommended, limit and that in every case the exposure to radiation should be minimized. Because the wartime project involved the widespread use of several types of radiation other than X-rays, scientists in the Manhattan Project devised other units to define the biological effects of these forms of radiation. Thus the rem (roentgen equivalent man) was defined as the quantity of radiation that produces the same biological effect in man as that resulting from the absorption of 1R of X-rays. Although standards for exposure continued for some years to be defined in terms of roentgens, the rem became a more common term as the analysis of radiation effects became more sophisticated. Another unit coming into greater use after 1953 was the rad, which is defined in terms of the energy absorbed per gram of tissue. As a measure of radiation effects, the rad is roughly equivalent to the roentgen. (Hereafter in this paper these units are referred to consistently as R, rem, and rad, respectively.)

By the end of World War II, a review of the 1934 standard was in order. Extensive radiation experiments with animals in several Manhattan Project laboratories had produced vast amounts of new data that deserved consideration. It was also clear that the rapid growth of nuclear technology after the war could pose radiation hazards of unprecedented dimensions. Recognizing the great increase in the number of radiation specialists in the United States, the American advisory committee in 1947 broadened its base to include personnel from the Manhattan Project, the new Atomic Energy Commission, and the Public Health Service. The National Committee on Radiation Protection (NCRP), as it was now called, set up seven committees to consider standards for various types of radiation exposure and sources. In June 1948, the committee on external doses recommended that the permissible dose of 0.1R

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per day be reduced by a factor of about two and that this figure be expressed in terms of a week, or 0.3R per week to the blood-forming organs, with higher levels permitted for less critical organs of the body. After extensive discussion at several international conferences, the new standard was also recommended by the International Commission on Radiological Protection (ICRP) in London in the summer of 1950.

Although the new standard was not based on the explicit assumption that there was a lower limit of exposure, or "threshold," below which radiation caused no real injury, some scientists argued for the existence of a threshold because injurious effects had never been observed following exposure to very small doses. Supporting the theory were the facts that human organisms were capable of some repair even when damaged by radiation and that the human race had existed for tens of thousands of years in a sea of radiation from cosmic rays, radioactive materials in their bodies, and radiation in the earth. In fact, background radiation was known to range from 0.04 to 0.40 rem per year worldwide in inhabited areas.

FALLOUT FROM EARLY CONTINENTAL TESTS

Because direct or "prompt" radiation from the detonation itself did not usually extend as far from ground zero as the lethal effects of thermal radiation and blast, the greatest danger of radiation exposure came from that induced in materials near ground zero and in fission products in the radioactive cloud. Ever since Alamogordo, scientists had been studying the composition and pattern of fallout from nuclear tests. Composition could be influenced by weapon design; the pattern, by meteorological conditions, the height of the burst, the energy released by the test, and

the nature of the surface at ground zero. In the first two test series at Nevada (Ranger in the winter of 1951 and Buster-Jangle in the fall), all but three of the twelve shots were detonated in the air at altitudes above one thousand feet, and the yields of these shots were less than two kilotons, or roughly one-tenth that of the Alamogordo test. Hence, fallout was minimal.

Unlike the Pacific tests, which were conducted for the Commission by a joint task force drawing on military personnel from all three armed services, the Nevada tests were directed by the Commission. The test director and his assistants were usually civilian scientists from Los Alamos, and Commission officials, mostly civilians, were directly involved in planning and conducting the tests. Once a test had been scheduled, precautions were taken to minimize the possibility of off-site damage. Detailed weather forecasts were made during the seventy-two hours before each test. Considering the type of detonation, the probable height of the cloud, and the wind speed and direction at various altitudes up to that height, the test group plotted the probable path of the radioactive cloud. If the cloud was likely to pass over an inhabited area or if rain or snow were likely for two hundred miles downwind, the test was postponed. If all conditions seemed favorable, warnings were dispatched to commercial airlines. Officials in nearby communities, ranchers, and state health officers were to be alerted that a test was about to take place, and radiation monitoring teams were deployed.

Although these precautions apparently prevented significant fallout near the test site in the Ranger series, one of the first tests did cause measurable fallout as radioactive snow in Rochester, New York, on February 2, 1951.

Apparently fission products from the shot had been carried up to 35,000 feet, transported eastward by the jet stream, and precipitated by the snow. The fallout seemed to pose no health hazard, but the Commission took immediate steps to set up an off-site monitoring network for the forthcoming Pacific test series (Greenhouse) that spring and for Buster-Jangle in the fall. By the time of the Tumbler-Snapper series in the spring of 1952, an extensive monitoring system had been established. Within two hundred miles of the test site, 180 men from the Commission, Los Alamos, the armed forces, and the U.S. Public Health Service monitored radiation. Fixed air sampling stations were set up in fifteen inhabited locations near the test site, and dust particles were trapped on gummed paper. Cloud-tracking aircraft teams followed the path of the radioactive air mass for about six hundred miles while two-man mobile monitoring teams were flown to positions under the cloud's path to take samples of airborne and settled dust. In addition, the Commission, with the help of the U.S. Weather Bureau, set up 121 fixed monitoring stations in all parts of the country. Samples of airborne and settled dust from these stations were sent to the Commission's Health and Safety Laboratory in New York City for processing. The Commission reported that none of the measurements of off-site fallout exceeded the NCRP level of 3.0R for external radiation over the ten-week period of the test series. The highest off-site reading reported by the Commission was 1.75R over ten weeks at a mine near the test site. The highest recording in cities and towns beyond the 200-mile range was less than .002R per hour for a few hours.

Of greater concern was the potential hazard of internal exposure to radioisotopes from fallout introduced into the body via the food chain from plants, meat, dairy products, or drinking water. Three elements--

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cesium, strontium, and iodine--were the most worrisome because they tended to concentrate in the body--strontium in bone, cesium in muscles, and iodine in the thyroid. Radioisotopes of these elements then could become internal emitters that would irradiate the body until they decayed into stable isotopes. Because the half-life of iodine 131 is only eight days, it was considered a serious but only short-term hazard in 1952. Cesium 137 and strontium 90 were thought to be more dangerous because their half lives were 25 years or more. When further experiments indicated that cesium 137 had not been present in fallout from the early test series in sufficient quantities to pose a health hazard, health physicists concentrated first on strontium 90. Not until the completion of the 1953 test series did scientists come to realize the potential hazard posed by these internal emitters.

Although the cumulative radioactivity produced by strontium 90 in the first three continental tests was calculated to be one hundred times less than that from natural background radiation, scientists realized that strontium 90 should not be permitted to accumulate to dangerous levels as weapon tests continued in Nevada and the Pacific. To that end, the Commission established project Sunshine in the fall of 1953. Initiated by Willard F. Libby, a radiochemist, who was a member of the Commission's general advisory committee, Sunshine drew on earlier theoretical studies completed in the Commission's project Gabriel in 1949. Under Sunshine, a worldwide network to monitor the presence of strontium 90 was established, and extensive basic research and analyses of data were performed by several of the Commission's laboratories and contractors.

Before 1953 concern about health hazards from nuclear tests was confined to those working in the atomic energy project. The public still looked upon the tests as something of a curiosity. That scientists could create such awesome devices suggested a competence that the ordinary citizen would not presume to challenge. Reassurances from the Atomic Energy Commission and the scientists conducting the tests that adequate safety measures were being taken reinforced this attitude.

The year 1953, however, brought new challenges in weapon development and new risks in testing. The challenges grew out of the grim race for the hydrogen bomb. Despite intensive efforts since 1949 by the scientists at Los Alamos to find a way to build such a bomb, not even a promising theoretical concept for designing the weapon appeared before early 1951. The George shot at Operation Greenhouse in the Pacific demonstrated that it was possible to use a fission device to achieve the enormous temperatures and pressures needed to "burn" thermonuclear fuel. Working under extraordinary pressure, the Los Alamos scientists had completed the design and construction of a full-scale test of a thermonuclear device, which was successfully tested at the Mike shot in Operation Ivy at Enewetak in November 1952.

Mike was a fearful demonstration of the power available in a hydrogen bomb. Light from the awesome explosion could be seen hundreds of miles away; the cloud rose to one hundred thousand feet, well into the stratosphere, and the yield of the explosion was more than ten megatons (ten million tons of TNT), or more than five hundred times the power of the Alamogordo test. Little immediate fallout, however, was found after the Mike shot, and all information about the test was highly classified.

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Furthermore, the device was merely a test of the physical theory; in no sense was it a deliverable weapon. Weighing more than eighty tons and housed in a good-sized building, Mike required elaborate cryogenics equipment to keep its hydrogen fuel in liquid form. With the knowledge that a hydrogen bomb was possible, scientists at Los Alamos steeled themselves for the last lap in the race--to have a deliverable weapon ready for testing in the Pacific early in 1954.

The drive for the hydrogen bomb placed new demands on the scientists who were planning the Upshot-Knothole test series, to be conducted at the Nevada site in the spring of 1953. Although full-scale tests of hydrogen bombs were then out of the question at Nevada, it was possible to conduct some of the diagnostic tests needed to design a deliverable hydrogen weapon. Furthermore, the accelerated pace of research on new types of fission weapons at Los Alamos since 1949 and tests designed by the new Livermore Laboratory in California had produced a backlog of crucial experiments, many of which, like the hydrogen bomb, could change the whole future of nuclear weapon development. The Commission pared the number of tests for Upshot-Knothole to ten, with some options for substitutions in later shots if earlier ones produced information warranting a change.

In order to accommodate the requirements of the laboratories, the test group decided to stretch the operational guidelines that Los Alamos had set for continental tests. To obtain precision in data collection, most of the shots were planned to be fired from 300-foot towers, an arrangement that produced much more fallout than did air drops. Of the seven tower shots in the series, five had yields greater than the Alamogordo test. Under these circumstances the test group clearly expected substantial

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fallout beyond the test site, but drawing on the experience in earlier series, there was confidence that the monitoring teams could quickly detect fallout patterns after each shot in the Upshot-Knothole series. The plan was to warn people in communities to take shelter if substantial fallout appeared to be coming in their direction. In fact, it was not always possible to contact isolated prospectors and ranchers.

The radioactive cloud from the first, or Annie, shot did move due east from the test site and dropped fallout on St. George, Utah, but the Commission reported that the maximum radiation level was no more than 0.026R per hour, or far below the guidelines set for off-site exposures. Nancy, the second shot, was somewhat larger than Annie and apparently dumped substantial amounts of fallout in sparsely populated areas northeast of the test site. Because monitoring teams had been stationed only in communities and took only a limited number of readings along roads, it was impossible to know precisely what the radiation levels were in the hinterland. In its public releases the Commission merely reported that there had been no fallout in populated areas, although it was admitted that the small number of residents at Lincoln Mine, Nevada, had been requested to remain indoors for two hours while radiation from fallout exceeded 0.5R per hour. The third through the sixth shots produced no radioactivity that was measurable in inhabited areas.

More radiation exposures, however, did occur during the high-yield shots that concluded the series. A wind shift at the time Simon was detonated on April 25 carried the radioactive cloud over two highways in Nevada. When fallout reached 0.46R per hour, the test director ordered

road blocks set up and about forty vehicles with interior readings of 0.007R per hour were washed at government expense.

By far the most serious was the fallout from the Harry shot on May 19. Postponed three days because of unfavorable weather, Harry was fired under what seemed to be perfect conditions. But a wind shift and a slight increase in wind velocity spread fallout in a pattern about fifty miles square over populated areas east of the proving ground. For the second time in a month road blocks were set up on major highways to monitor motor vehicles. At 9:10 a.m., about four hours after the shot had been fired, readings as high as 0.32R per hour were being recorded at the road blocks. At that time Edward S. Weiss, the Public Health Service officer stationed in St. George, called the sheriff's office and radio station to warn people in the area to take cover. Local schools kept children indoors during the morning recess and the washing of contaminated cars in St. George was suspended. By 9:40 a.m. most of the population in St. George was under cover and the community came to a standstill. The all-clear came before noon when the first officials from the test site arrived to look over the situation. Because of the understandable tension among the residents, Weiss was ordered to remain in the area for several more days. During that period he considered collecting milk samples from local dairies to check for radioactivity, but because of the uneasiness in the community, Weiss concluded that such a survey might create alarm. For that reason he limited his investigation to a few samples of milk purchased in local stores. From measurements at St. George the test group later estimated that the maximum amount of external exposure that could have been received at St. George was 6.0R and 5.0R at Cedar City. Scientists later estimated that children living near the test site received thyroid doses from iodine 131 ranging from 30 to 240 rad.

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PUBLIC AND PRIVATE CONCERNS ABOUT FALLOUT

Although many people in these Utah communities were unnerved by the incident, they were reassured by statements from the test group that the radiation exposure had been below hazardous levels. Most people did not complain about having to remain indoors or waiting at road blocks. Although there was neither public alarm nor open protest in the communities, individuals did complain that fallout had caused physical injuries or disabilities. Only two very mild congressional inquiries resulted from the Simon and Harry incidents, and both of these took the form of requesting reassurance rather than registering a protest. In both instances, Commission officials and the test group were able quickly to convince the Congressmen that adequate precautions had been taken to assure public safety. Very few newspapers outside the immediate area covered the incidents, and most of these stressed the Commission's reassurances. Incomparably more troublesome were the deluge of letters and a flurry of newspaper and magazine articles speculating on whether the seemingly unusual number of severe tornadoes occurring across the nation that spring were caused by the Nevada tests. The Commission's public information staff was still answering tornado inquiries long after the fallout incidents had been forgotten.

Although public alarm had been avoided, the Commissioners were privately concerned about the fallout from the larger shots in the series. On May 13, 1953, they learned that the total potential lifetime dose for inhabitants in thinly populated areas following the Simon shot had been as high as 10.0R. Another instance of long-distance fallout occurred near Troy, New York, where rain-out delivered a potential lifetime dose of 2.0R. Thyroid doses from the rain-out were later estimated to have been as high as 15 rad. The

Commissioners also received troubling reports that sheepmen who customarily wintered their herds north of the test site had encountered unusually heavy losses after trailing their sheep to an area west of Cedar City, Utah, for shearing during April. Losses ranged up to 30 percent for newborn lambs and 20 percent for ewes or mature sheep. Because the winter range had received substantial fallout from the Nancy shot on March 24, there was a possibility that radioactive fallout could have been a factor in the sheep deaths. Unfortunately most of the dead sheep had been disposed of before veterinarians and radiation specialists arrived on the scene, but many of the surviving sheep in the affected herds showed lesions on the face and back after shearing. State and local veterinarians were unable to diagnose the malady, and those from the Public Health Service and Los Alamos were not certain whether the lesions were caused by fallout. Arrangements were made to sacrifice some of the surviving sheep for detailed biological studies and further radiation experiments on sheep were started at the Commission's Los Alamos and Oak Ridge laboratories.

The fallout question became even more pertinent the following week when the test group asked the Commission to add an eleventh shot to the series. Design work had just been completed at Los Alamos on some new ideas for the deliverable thermonuclear weapons to be tested in 1954. Because Los Alamos had finished this work earlier than expected, the new idea could be tested at Upshot-Knothole rather than in a special single-shot series in the Pacific in the autumn of 1953. Testing the device in Nevada would save time and a large amount of money, but the yield would be more than 60 kilotons, or about 30 percent greater than Simon. Concerned about the potential hazards but even more about the need for the shot, the Commission

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took the decision to President Eisenhower who, with some misgivings, approved the test.

The eleventh shot, called Climax, fortunately performed close to prediction. Although the yield was 61 kilotons, off-site fallout was far below that of Simon and Harry and the test provided the information needed for the hydrogen bomb test. This successful outcome, however, did not end the matter for the Commissioners. They ordered a halt to all planning for Nevada tests until a special study group of Commission officials and Los Alamos scientists had re-examined the advantages and hazards of continental testing.

One of the issues to be resolved before Nevada testing could be resumed was whether the Upshot-Knothole series had caused the sheep kill. Commission personnel at the test site were fully aware that the future of continental testing might hang on the results of the investigations already started. The studies completed during the autumn of 1953 concluded that neither the level of external radiation, nor radiation burns on the sheep's skin, nor radiation of the sheep's thyroid from iodine 131 in the fallout could have caused the deaths. The supporting data presented by the Commission's laboratories were impressive and seemed conclusive. It seemed much more likely that the excessive number of deaths resulted from the extremely dry weather that left the herds badly undernourished that spring. Although the results were favorable, Commission officials in the field threw the best possible light on the findings, not only to show the general public that the tests could be conducted safely, but also to reassure the Commissioners, some of whom remained to be convinced. The press announcement released in January 1954 said only that fallout had "not been responsible"

for the deaths, without exploring the question of whether it might have been a factor. The announcement also glossed over the fact that scientific opinion on the question was not unanimous.

In the meantime, the special study group had investigated all aspects of Nevada testing and had come up with recommendations that seemed to impose tighter restrictions without unduly hampering test operations. First, the committee set forth guidelines for justifying the need for shots, controlling or reducing fallout from potentially hazardous shots, prohibiting marginal shots under questionable weather conditions, and imposing yield limitations on surface, tower, and airborne shots. Second, the committee proposed a "planning maximum" of ten to fifteen shots in one year at the Nevada site. Third, the committee advocated lowering the maximum permissible off-site exposure from 3.9R over thirteen weeks to the same amount integrated for the entire year. On June 30, 1954, more than a year after the last shot in the Upshot-Knothole series, the Commission approved continuation of Nevada tests, subject to the restrictions proposed by the study group but without any limitation on the number of tests in any one year. On this basis, the test group made plans for the next continental test series scheduled for the spring of 1955.

TROOP PARTICIPATION IN CONTINENTAL TESTS

The dual code names given to the test series beginning with Buster-Jangle highlighted the fact that these operations no longer had the single purpose of testing weapon devices but now had a second purpose of providing a nuclear explosion for use in studying the effects of these detonations. Strongly opposed by the test group because they complicated planning and

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reduced flexibility in execution, tests for weapon effects had become increasingly important as groups outside the test organization began to realize the implications of nuclear warfare.

The greatest pressure for effects tests came from the military services, not only to observe the effects of nuclear weapons on military equipment, but also to train military forces for nuclear combat. Also of great impact were the needs of the Federal Civil Defense Administration for accurate data on the effects of nuclear blasts on many of the commonplace articles of civilian life as well as blast and fallout shelters. Lastly, but also significant, were the requests of the U.S. Public Health Service and the Commission for controlled experiments to observe the biological effects of nuclear detonations on plants and animals.

Of these, the military projects posed the greatest hazard because they involved large numbers of military personnel in operations very close to ground zero. The first participation by military forces occurred in the Buster-Jangle series, where more than 5,000 troops witnessed the Dog shot from a distance of seven miles. Following the detonation, a battalion combat team moved to within five hundred yards of ground zero before encountering the maximum allowable radiation level of 1.0R per hour. The Commission had complete control of radiation monitoring and provided forty-five monitors, who led the troops into the detonation area.

Troop participation increased significantly in the Tumbler-Snapper series in the spring of 1952. More than seven thousand troops took part in four of the tests. The troops usually observed the detonation at about seven thousand yards, with small numbers moving closer than a thousand yards

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from ground zero as conditions permitted after the shot. In the first tests, radiation monitoring was performed by the participating troops with supervision by the Commission's test personnel but, by the last shot, the Commission had completely delegated responsibility for radiation safety to the Army.

In Upshot-Knothole and in all subsequent series, the Army accepted full responsiblity for radiation safety. More than 17,000 military personnel participated in six of the eleven shots in Upshot-Knothole. The distance required for observation of the tests by large numbers of troops was now reduced to 3,500 yards or less, with smaller numbers maneuvering close to ground zero. In two of the tests, Nancy and Badger, wind shifts occurred that brought fallout as high as 14.0R per hour into the maneuvering area.

FALLOUT IN THE THERMONUCLEAR AGE

Eight weeks after the last shot in Upshot-Knothole, the Soviet Union announced in August 1953 that it had detonated a hydrogen weapon. Although the Soviet device was probably a fission weapon that "burned" some thermonuclear fuel, the Commission, for security reasons, did not attempt to correct the public interpretation that the Soviets had produced a true thermonuclear weapon capable of delivery by aircraft. Following so closely upon the Mike shot, which was not the prototype of a deliverable weapon, the announcement of Joe 4 (the fourth Soviet nuclear test) suggested to many Americans that the Soviet Union had overtaken the United States' lead in nuclear weapon development.

Joe 4 greatly increased the pressure on Los Alamos' preparations for the Castle series, which would test several thermonuclear devices early in

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1954. The enormous force of Mike had convinced the scientists that thermonuclear shots in the megaton range were too powerful to be conducted at Enewetak without threatening the extensive facilities that had been constructed there. Mike had destroyed an entire island in the Enewetak atoll and had damaged facilities on other islands. With the much larger tests contemplated for Castle, even the permanent facilities at the southern rim of the atoll would be threatened by thermonuclear tests in the northern islands. The test group therefore decided that the large tests in Castle would be fired at Bikini, which had not been used since Crossroads, while the main operational base remained at Enewetak. When additional areas were added to the exclusion zone for the tests, the two atolls were in the center of a huge testing area of more than 67,000 square miles, or roughly the size of New England.

For the Bravo shot, the first in the series, all usable equipment was moved to the southern rim of the atoll and all civilians and military personnel except the firing party were evacuated on ships to a distance of thirty miles. Almost from the moment Bravo was fired on the morning of March 1, 1954, it was evident that the detonation had been far more powerful than the six megatons predicted. In fact, the yield was later determined to be fifteen megatons. Fallout within the test area was also much heavier than expected. As far out as thirty miles, the ships of the task force received heavy radiation and were ordered out to a distance of fifty miles. Even after activating washdown equipment, ship commanders reported radiation levels as high as 5.0R per hour on decks and 25.0R per hour in deck drains. Personnel were forced to stay below decks in the stifling heat for more than four hours until radiation levels declined. When the ships returned

to Bikini, they could not enter the lagoon because of high levels of radiation. In order to evacuate the firing party and to complete other critical operations, the joint task force commander had no choice but to double the maximum permissible exposure of 3.9R for critical personnel such as helicopter pilots, flight deck personnel, and boat pool operators.

The massive cloud, which triggered thunderstorms and squalls throughout the area, rose more than twenty miles into the stratosphere while fragments at lower elevations began moving in a northeasterly direction. Unfortunately, the cloud did not move precisely in the path predicted by the painstaking preshot calculations but instead drifted over several inhabited islands just outside the eastern border of the exclusion area. Thirty-one American military personnel and 236 islanders from Rongelap, Rongerik, Ailinginae, and Utirik were evacuated to avoid further radiation exposure. On the island of Rongelap, just one hundred miles east of ground zero, where most of the islanders lived, average readings were 0.375R per hour while some soil samples were as high as 2.2R per hour. From these data, radiation safety personnel computed that the islanders received a whole-body gamma dose of 175 rad on Rongelap, 69 rad on Ailinginae, and 14 rad on Utirik.

The final and in many ways the most significant radiation incident from Bravo was not discovered until March 14, when a Japanese fishing vessel, the Lucky Dragon, arrived in Japan with all twenty-three members of the crew suffering from radiation exposure. The vessel had been about 82 nautical miles from Bikini at the time of the Bravo shot, or just beyond the eastern boundary of the exclusion area. Although the fishermen suspected that the blast was a nuclear weapon, they did not know there was any danger. Because they did not bother for several days to wash away the white powdery substance

that fell on the ship, all received extensive radiation, and one member of the crew subsequently died of what was widely believed to be radiation effects. Because the Japanese would not permit personnel from the Atomic Bomb Casualty Commission or other American experts to examine the crew members, it was impossible for Americans to verify the extent of radiation injury.

The incident received sensational treatment in the Japanese press and in time brought to world attention the dangers of radioactive fallout, particularly from large thermonuclear weapons. President Eisenhower and other members of his administration were deeply impressed by the fearsome implications of thermonuclear weapons, not only for the security of the United States but also for the welfare of the human race. In the face of the growing Soviet threat, however, there seemed no choice but to continue development.

NEW DEPARTURES AT TEAPOT

The next continental test, called Teapot, was scheduled to begin in the spring of 1955, almost two years after Upshot-Knothole. In that interval the weapon laboratories at Los Alamos and Livermore had again accumulated a large backlog of tests that were urgently needed to develop a variety of new weapons, especially small weapons, both fission and thermonuclear. Looking toward the reduction of the large amounts of fallout associated with tests in 1953 and 1954, the laboratories were also beginning to explore new designs that would reduce the ratio of fissionable to thermonuclear fuel in weapons so as to lessen fallout. The Commission had approved an ambitious program for fourteen shots at Teapot, but nine of these were less than ten kilotons and all the high-yield shots were fired on towers 400

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or 500 feet high. As a further precaution against heavy fallout, the new guidelines for continental test operations developed after Upshot-Knothole were now in effect. Among these was the decision to reduce the maximum permissible exposure for off-site personnel to 3.0R for the entire year.

Although more than eight thousand military personnel participated as observers or in training exercises associated with twelve of the shots at Teapot, maneuvers involving large numbers of troops were confined to only two shots, the Marines at Bee on March 22 and the Army at Apple II on May 5. For the remaining ten shots, military personnel participated only as observers. No central records of film badge readings were kept for military personnel, but about one hundred cases of exposure above 3.0R were recorded.

The most significant change in test procedures at Teapot was the increased attention given to off-site monitoring and the formal, largely independent role assigned to the U.S. Public Health Service. The Service had first begun to respond to the health hazards of radiation in 1948, when it assigned two of its officers to a three-year course offered by the armed services in radiological defense engineering. The following year the Service began developing better measurement instruments for monitoring radioactivity in the environment and began the first of several studies to determine the pattern of low-level radioactivity emission from a variety of Commission sites involved in the processing and production of fissionable materials. By 1950, the Public Health Service had organized a program for radiation health training, which became part of the activities of the Environmental Health Center in Cincinnati, Ohio. Systematic training in the public health aspects of radiation hazards was made available to other federal, state, and local agencies.

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About a dozen officers of the Public Health Service had assisted, at the Commission's request, in collecting fallout data at fixed stations in small communities just outside the test area during the Upshot-Knothole series. For the first time, complete fallout records were made for an entire test series in these communities. The Public Health Service officers, however, were under the complete control of the Commission and the test organization, and all of the records they collected had to be turned in to the test group as classified information. Some of the monitoring equipment used had not been field tested and did not operate properly, monitoring procedures were not always practical under field conditions, and relations with local residents were often difficult when health officers were forbidden to discuss any of their readings with the public.

By the time of the Teapot tests in 1955, the Commission had signed an agreement with the Public Health Service to participate in radiation monitoring in a more formal way. Sixty-six officers from the Service participated in Teapot and assisted in collecting detailed information that was later published on each of the fourteen shots. During Teapot, the officers were permitted to discuss their readings with residents and provided information about the tests. The Public Health Service placed much greater emphasis than had earlier groups on readings from film badges, many of which were exposed on fixed objects in the area rather than on individuals.

The Public Health Service provided similar off-site monitoring support for Operation Redwing in the Pacific in 1956 and for Plumbob, a twenty-four-shot series at Nevada in 1957. By this time the Service was preparing its own independent reports on fallout data, which were available to the public,

in place of the earlier classified reports that went only to the test groups. The Service also established a Medical Officer Liaison Network to investigate cases of illness or injury allegedly due to fallout and a permanent office of the Radiological Health Program at Las Vegas. The Service was available fulltime to monitor off-site radiation, not only from nuclear weapon tests but also from nuclear reactor experiments and the detonation of nuclear devices for peaceful purposes in the Commission's Plowshare program.

The entry of the Public Health Service into the field of radiation monitoring provided much-needed support to the Commission in terms of both manpower and technical knowledge. In the long term, however, the Service's most significant contribution was to change the whole conception of the federal government's role in radiation monitoring. During the first decade of the nuclear age, the Manhattan Project and the Atomic Energy Commission had looked upon the dangers of radiation exposure as a problem in industrial safety. The task was primarily to protect the health of persons working in the laboratories, production plants, and at the test sites. Similarly, the Commission did try to protect the public from hazards that might emanate from these operations.

After Upshot-Knothole and the Castle tests, however, it was evident that fallout was more than a conventional problem in industrial health. It had become a general hazard of the nuclear age, one that threatened the health and the lives of people in all parts of the world. Public adjustment to this new "fact of life," as Commissioner Willard F. Libby referred to it, was very slow; nor did persons in the atomic energy project immediately understand the full implication of the situation. The Public Health Service,

with its extensive experience in studying all types of health problems on a national rather than a single-industry level, provided essential leadership in formulating a new approach to the measurement and control of radiation hazards.

Despite the Atomic Energy Commission's attempts to allay public concern about fallout in the years after Operation Castle, the subject had become a national issue by 1957. No longer confined by security classification to persons inside the atomic energy establishment, scientific and technical information related to fallout and associated radiation hazards was becoming public knowledge. The opening of these subjects to broad scientific investigation had started with Project Sunshine, then proceeded through a wide range of research programs supported by the Commission in the national laboratories, universities, private institutions, and federal agencies such as the Public Health Service.

The broad scope of this effort and the magnitude of data already produced became evident during the hearings held by the Joint Committee on Atomic Energy in the spring of 1957. The Commission reported that it was supporting 41 research projects on the sampling and analysis of fallout involving 107 scientists at a cost of $1.2 million; 102 research projects on the biological hazards of fallout involving 442 scientists at a cost of $5.6 million; 108 projects on the effects of radiation on humans, mammals, and other organisms at a cost of $9.2 million; 30 projects on the treatment and methods of ameliorating radiation effects at a cost of $1.3 million; and 44 projects on the genetic effects of radiation on both humans and other species at a cost of $1.5 million. Although much of this research

had been initiated by university scientists rather than by concerns about fallout, it did provide a useful data base for applied studies.

The hearings not only gave a large number of scientists an opportunity to testify, but also provided for panels in which experts of different opinions could discuss the significance of the voluminous data presented. (The published testimony and related documents totaled more than two thousand pages.)

Unlike some congressional hearings that become adversarial and controversial, the sessions in 1957 were exploratory and tentative in tone. There was general agreement that the nature and intensity of fallout depended on the type of device detonated and that fallout was not uniformly distributed. There was substantial, but not complete, agreement as to how much radioactive debris was in the environment, how and where it was distributed, and how much had reached humans. Most of the scientists agreed that any amount of radiation, no matter how small, would increase the rate of genetic mutation, but many disagreed on whether there was a "threshold" for somatic effects such as leukemia, bone cancer, or life shortening, even though the Atomic Bomb Casualty Commission had already found leukemia in victims of Hiroshima and Nagasaki. The participants accepted the fact that there were limits to the amount of radioactivity that could be tolerated in the environment and that the matter of determining the tolerance limit for present and future generations was a moral as well as a scientific question. Data did indicate that human exposure to radioactive fallout, including strontium 90, from tests already completed would be less than one-tenth that from "natural background" sources, but there was no agreement on what the statement meant in terms of long-term health hazards.

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FALLOUT AND THE TEST MORATORIUM

On one point all participants in the hearings agreed--that the radiation effects of a full-scale nuclear war would be "catastrophic" for the human race. The specter of nuclear war had haunted President Eisenhower since his first secret briefing on Mike in 1952. In the months following the Bravo shot in 1954, he prodded his administration to consider supporting a moratorium on nuclear testing. When this effort collapsed in the face of opposition from the Defense and State Departments and the Atomic Energy Commission, Eisenhower appointed Harold Stassen to the new post of Special Advisor to the President on Disarmament. With the help of Stassen and Henry Cabot Lodge, the American Ambassador to the United Nations, the President pursued both the test ban and disarmament through the United Nations and diplomatic channels. In 1955 he discussed both proposals with Soviet Premier Bulganin at the Geneva summit conference.

In the 1956 presidential campaign, the Democratic candidate, Adlai Stevenson, advocated a treaty banning the use of hydrogen bombs, and the debate over disarmament and a test ban continued into Eisenhower's second term. During these years, the administration declared its willingness to suspend nuclear tests as part of a nuclear disarmament agreement. In the absence of such an agreement, however, the President refused to consider a test ban. In the summer of 1958, senior scientists from the United States, the United Kingdom, and the Soviet Union met in Geneva to discuss the technical aspects of policing a test ban. During these meetings, the President announced that the United States was prepared to negotiate a test ban agreement and would voluntarily suspend all weapon testing from the beginning of the negotiations. As a result, an unpoliced moratorium

went into effect on October 31, 1958, when representatives of the three nations met in Geneva to begin the conference on test cessation.

The announcement of the moratorium offered at least a temporary solution to the problem of fallout, but the moratorium did not come without a price. In anticipation of the President's action, the Atomic Energy Commission had embarked on an accelerated schedule of weapon tests both in Nevada and the Pacific in 1958. The first phase of Operation Hardtack from April through August included twenty-nine tests at the Pacific Proving Ground and two tests of thermonuclear warheads in the megaton range on rockets at Johnston Island in the Pacific. The second phase, at the Nevada Test Site beginning in September, involved eighteen detonations, including four underground shots and ten shots with the device suspended about 1,500 feet above the surface by a balloon. Most of the shots were of very small yield, many only a few tons of TNT, and the fallout appeared minimal.

During the same year, 1958, the United Kingdom detonated five nuclear devices, three of which were in the megaton range, at its test site in the South Pacific. The Soviet Union in the same period fired twenty-five devices at its Arctic and Siberian test sites. Nine of these shots had been in the megaton range. By the end of the year, the United States had fired a total of 151 test devices since Alamogordo. The British had completed twenty-one tests, and the Soviet Union, fifty-five. Just two years of nuclear testing by these three nations had released fallout equivalent to that produced by detonating 40 megatons of fission weapons, or more than 40 percent of the fallout from nuclear tests since 1945. Much of the radioactivity produced by these tests had been carried to the stratosphere,

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where it would remain for one to five years before falling out in east-west bands around the earth, mostly in the northern hemisphere.

The accelerated pace of testing in 1957 and 1958 and the alternatives to testing that might be devised during the moratorium were the subject of discussion at a second series of hearings before the Joint Committee on Atomic Energy in the spring of 1959. Scientists testifying at the hearings still considered strontium 90 and cesium 137 the greatest hazards of world-wide fallout (as distinguished from fallout near test sites). But several short-lived isotopes, such as strontium 89, iodine 131, barium 140, and zirconium 95, were cited as potentially hazardous. The rate of deposition of strontium 90 had increased in the spring of 1959 in the northern hemisphere. Likewise, the content of strontium 90 and cesium 137 in food had risen since 1957, even more rapidly than the total fallout, a fact that suggested that under certain conditions strontium 90 was being taken up directly by humans from food without going through the soil cycle. On the subject of biological effects of radiation, evidence was presented suggesting that the rate of dose might have some influence on the magnitude of genetic effects, but the biological significance of low levels of radiation was still unknown. No agreement was reached on whether or not there was a threshold for somatic effects such as cancer and leukemia.

NEW PATTERNS OF FEDERAL CONTROL

In 1959 most of the research on biological effects of radiation and fallout monitoring was still being sponsored by the Atomic Energy Commission. The Commission's budget for these activities was approaching $20 million per year. Since 1947 the Commission had spent $125 million in biomedical

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radiation research. In its monitoring efforts, the Commission operated a worldwide gummed-paper sampling program at one hundred stations in thirty-seven countries. There were also sixty-four soil sampling stations in foreign countries and seventeen in the United States. The Commission maintained four stations throughout the world to sample air at altitudes up to 90,000 feet.

By comparison, the radiation research program of the Public Health Service was still small and in the process of formulation. In 1958 the Public Health Service consolidated all of its work on radiation control in the new Division of Radiological Health within the Bureau of State Services. In 1959 the Division's annual budget was still less than $1 million, but other elements of the Public Health Service--namely, the National Institutes of Health and the Communicable Disease Center--also had limited funding to support research.

When the test moratorium went into effect in 1958, the Service was already operating four monitoring networks. The Radiation Surveillance Network established in 1956 in part with Commission funds provided daily, twenty-four hour air samples from forty-five stations throughout the United States. In 1957 the Service had set up a small monitoring network of twelve stations to develop sampling and analytical techniques to measure concentrations of strontium 90, cesium 137, and iodine 131 in milk. The National Water Quality Network established in 1957 provided samples from fifty stations along the nation's major waterways to determine water quality. From radioactivity associated with dissolved solids, the Service was able to make some gross estimates of radiation levels. The largest of all the Service's monitoring systems was the National Air Monitoring Network set

up in 1953 to collect data on air pollution throughout the nation. The Service had two hundred forty sampling stations, of which about one hundred seventy-five operated in any one year, in seventy-three large cities and thirty-seven non-urban areas. The stations, manned by Federal, state, and local agencies, collected daily twenty-four hour samples of suspended particulate matter.

The test moratorium in 1958 gave the Congress and the Executive Branch an opportunity to reassess the adequacy of federal programs for controlling radiation hazards. The Joint Committee hearings in 1959 produced another three thousand pages of testimony and supporting documents. Early in 1959 the National Advisory Committee on Radiation, appointed by the Surgeon General the previous year, submitted a report that reviewed all federal activities in terms not just of monitoring radiation effects of fallout but rather of controlling health hazards from all radiation sources. In examining many aspects of this complex problem, the committee focused on the fact that most of the authority for regulating the use of radiation in the United States rested with the Atomic Energy Commission, which was also the principal agency charged with developing and promoting the uses of atomic energy. In the committee's opinion, there was a fundamental question of whether a single agency should serve both as promoter and regulator. The committee recommended that responsibility for protecting the nation against radiation hazards be assigned to one agency of the federal government, preferably the Public Health Service, and that that agency be charged with "promulgating uniform, national standards of radiation protection."

A few days after release of the advisory committee's report, President Eisenhower asked the Bureau of the Budget to conduct a special study of

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federal administration of radiation control. Although the central question appeared to be whether federal authority would remain with the Atomic Energy Commission or be transferred to the Public Health Service, the study resulted in an Executive Order on August 14, 1959, establishing the Federal Radiation Council. Members of the Council were the Secretaries of the Departments of Health, Education, and Welfare; Agriculture; Commerce; Defense; Labor; and the Chairman of the Atomic Energy Commission. The Council's functions were to advise the President on radiation matters affecting health, to guide federal agencies in formulating radiation standards, and to help the federal agencies to cooperate in radiation control activities. The Council also had a technical staff that organized study projects using personnel from the agencies. Clearly a compromise falling far short of the advisory committee's recommendations, the Federal Radiation Council was not given the power of a single federal authority on radiation control. During the 1960's, however, the Federal Radiation Council did draft several guides designed to protect workers and the general public from radiation. In 1970 the President transferred authority to issue these guides to the Environmental Protection Agency under Reorganization Plan No. 3.

RESUMPTION OF NUCLEAR TESTING

On August 31, 1961, Chairman Khrushchev announced that the Soviet Union was resuming nuclear testing, and the first of an intensive series of Soviet tests began the next day and continued through 1962. Since the spring of 1961, the Kennedy Administration had been considering the possibility of such a development, and some leaders of the Administration were urging that the United States begin to make preparations to do likewise. President

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Kennedy, however, was reluctant to take such a step and even made a private appeal to Khrushchev to reverse his decision after the first shot was fired.

As the Soviet tests continued during the fall, the Commission's laboratories moved as quickly as possible to resume test operations in Nevada. Although no devices were actually ready for testing, the laboratories had some plans for such a contingency, and the first shot was fired in an existing tunnel more than 1,300 feet underground on September 15, 1961. To eliminate the hazards of fallout, most of the ninety-eight announced tests conducted at Nevada during the next sixteen months were underground. There were four surface detonations, two were cratering shots, and two were part of the Plowshare peaceful uses program. Of the ninety-eight tests, twenty-three were announced but not specifically named. Of these twenty-three tests, seventeen released small quantities of radioactivity but none were detected offsite. Of the ninety-eight announced tests, ten released sufficient radioactivity to be detected off-site. Most of the tests involved devices with very low yields and there was troop participation at only one test, at Little Feller 1 on July 17, 1962.

Even as test operations moved into high gear in Nevada, the President was still extremely reluctant to approve the resumption of atmospheric tests in the Pacific, despite strong pressure from the Joint Committee on Atomic Energy, some members of Congress, and a substantial segment of the American public to do so. Only after Kennedy was fully convinced that the step was necessary did he approve plans for Operation Dominic, which began at Christmas Island in the Pacific on April 25, 1962. During the next seven months the Commission conducted thirty-six announced tests in the Pacific. All of them, except for one underwater shot, were in the

atmosphere and five were very high-altitude detonations. The last of the high-altitude tests at Johnston Island on November 4, 1962, marked the end of atmospheric testing by the United States. In the autumn of 1963, the Limited Ban Treaty prohibiting nuclear tests in the atmosphere, underwater, or in outer space came into effect. All subsequent American tests have been underground with every effort made to avoid the venting of radiation to the atmosphere. In the spring of 1978, the Department of Energy reported that, although radiation from seventeen underground shots had been detected off-site from December 12, 1963, until December 18, 1970, only the last of these, Baneberry, resulted in any significant exposure, and the maximum exposures were all well below the standards in the Radiation Protection Guide of the Federal Radiation Council.

When it became apparent in the autumn of 1961 that the Soviet Union had embarked on an extensive series of tests in the atmosphere, the Atomic Energy Commission, the Public Health Service, and other federal agencies moved quickly to reactivate and expand the radiation monitoring networks. The Public Health Service enlarged the Radiation Surveillance Network from forty-five to seventy-two stations in the fifty states, Guam, and Puerto Rico. By this time, the Service was routinely operating the Pasteurized Milk Network of sixty-two stations, with at least one station in almost every state. Samples were taken daily by state and local milk sanitation agencies from tens of thousands of American farms and were shipped for analysis to the Service's Southwestern, Southeastern, and Northeastern Radiological Health Laboratories. In 1961, the Service had started an Institutional Diet Sampling Program, which sampled all food consumed in twenty boarding schools and institutions feeding children and young adults to age eighteen. Average daily intakes of iodine 131, strontium 89 and 90, and cesium 137 were

recorded. The National Water Quality Network was expanded from fifty to one hundred twenty-five sampling stations during the test period, and the Service enlarged its efforts to measure strontium 90 in human bones and iodine 131 in human thyroids from autopsies at selected medical centers throughout the United States. These monitoring and research activities continued to grow during the 1960's. On January 1, 1967, when the Division of Radiological Health became the National Center for Radiological Health, the new center had a budget of more than $20 million. In 1968 the Center became the Bureau of Radiological Health.

The expanded monitoring networks made it possible to collect larger quantities of reliable data on the radiation effects of fallout than had been possible before the moratorium. Because virtually all of the Soviet tests were conducted in the atmosphere, it was estimated in 1963 that three-fourths of the long-term fallout in the United States would come from Soviet tests. Since testing began in 1945, fission products from Soviet tests had been about twice those from American and British tests combined.

NEW APPROACHES TO FALLOUT RESEARCH

Once the Limited Test Ban Treaty became effective, the health hazard of fallout from weapon tests began slowly to decline as fission products from the upper atmosphere were precipitated. The only detected weapon tests in the atmosphere were conducted by nations not signatory to the treaty. By the end of 1979, France had conducted thirty-one atmospheric tests; China, twenty-one; and India, one. The annual whole-body dose from global fallout was estimated to decline from 0.13 rem per person in 1963 to 0.04 in 1969. The Public Health Service's Radiation Surveillance Network

was renamed the Radiation Alert Network in 1967 to indicate that it was now operated only in quick response to monitor significant releases of radioactivity from foreign weapon tests or nuclear accidents.

As the number of atmospheric tests declined in the 1960's scientists who were studying the radiation effects of fallout had fewer opportunities to collect new data. It was now possible, however, to give greater attention to the vast amounts of information that already existed, to assemble statistics from a variety of sources, to try to resolve problems of comparability, and to subject the data to rigorous analysis. The 1960's became a decade for reanalysis of data, reassessment of assumptions, and at times controversy among some of the scientists involved.

Reanalysis seemed in order because, in the concerted effort to develop new weapons during the 1950's, test personnel had not given priority to data collection; nor had there always been time to explore the long-term implications of the data accumulated. Assumptions laid down hurriedly in the early 1950's seemed less valid as more scientists looked at the fallout problem from different perspectives and examined these assumptions in the light of new information. Controversy arose because scientists were no longer dealing with the collection of "facts" but rather with the analysis of data, some of it more than fifteen years old, in an effort to find in its subtleties some evidence of health effects.

Much of the analysis of fallout data in the 1960's involved the search for causal relationships between exposure to low-level radiation and the incidence of cancer, particularly thyroid cancer and leukemia. In this type of investigation the statistical analyst and the epidemiologist had

prominent roles. By 1960 the Atomic Energy Commission had established a fallout studies branch staffed, not by health physicists and physicians, but by scientists from various fields with strong analytical talents. Harold A. Knapp, Jr., an analyst with a doctorate in mathematics, joined this group in 1960 and soon became deeply immersed in reviewing all the information he could find on the concentration of iodine 131 in cow's milk and its function as an internal radiation emitter as it collected in the thyroid. Knapp was struck by the fact that surprisingly high levels of iodine 131 had been measured in milk samples in several midwestern cities at times when levels of external exposure were very low. Because no milk samples had been systematically collected near the test site during the periods of greatest fallout in the 1950's, Knapp used data collected by the British on the radioiodine content of milk following the Windscale reactor accident in England in 1957. From the Windscale data and other sources Knapp devised a mathematical formula that he applied to the maximum dose rate of fallout in order to estimate radioiodine concentration in milk in that locality.

When Knapp applied this formula to the dose rates reported at St. George after the Harry shot in 1953, he calculated that the concentration of iodine in milk had probably reached very high levels and that infants who drank this milk during the month following the shot probably received 120 to 440 rad of radiation to the thyroid. Knapp's calculations also indicated that "the dose to the infant thyroid from I-131 concentrated in milk by the cow was in the range of 60 to 240 times the direct dose to the thyroid (and the whole body) from external gamma radiation."

Knapp's conclusions were sensational because they suggested that throughout the entire period of intensive testing scientists had seriously underestimated the biological effects of iodine 131 in fallout. The difficulty with Knapp's findings, as he himself admitted, was that they were only very rough estimates that depended for their validity on arbitrary assumptions about the actual dose rates in specific localities, the nature of the terrain and vegetation where the fallout occurred, weather conditions at the time of fallout, the precise location of the grazing cows, their health, the time that elapsed before the milk was consumed, and a host of other factors. Thus Knapp's paper was much more an exercise in mathematical computation than a biological study of radiation effects. As a result, Knapp's studies failed to find acceptance among his colleagues. After three years of running debate with his superiors, Knapp left the Commission in 1963.

It was ironic that by the time the iodine 131 hazard was discussed for the first time in open hearings before the Joint Committee on Atomic Energy in the spring of 1963, residual fallout from earlier tests no longer contained traces of the isotope. Even then the subject was not discussed at length although the printed transcripts contained several papers, including Knapp's, that attempted to relate gross exposure data to iodine content. The hearings did stimulate renewed interest within the Atomic Energy Commission and the Public Health Service in investigating the incidence of cancer in the Utah-Nevada area. The Commission agreed to put up more money for research and the Public Health Service's Division of Radiological Health laid plans to expand the morbidity and mortality studies already in progress in the area.

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Edward S. Weiss, who had been the radiation monitor in St. George during the Harry shot, coordinated much of the field research with state and local health officials. The Division of Radiological Health had started biological surveillance activities in the two Utah counties nearest the test site in 1957, when Weiss began collecting death certificates involving leukemia for the years after 1950. When analysis of these certificates indicated that more leukemia deaths had occurred than would have been expected on the basis of statistical averages, the Division arranged to have epidemiologists study the medical records. Their study revealed that three of the twenty-eight observed cases were of doubtful validity and that eight were of a type of leukemia not attributable to radiation. The size of the sample and the apparent excess were judged too small to provide definite evidence that fallout had caused the excess, and the study was not published.

The first priority for the Utah-Nevada health studies was to investigate the incidence of thyroid disease in the fallout areas. The interest in thyroid studies stemmed not only from the disquieting information about iodine 131 presented at the 1963 Joint Committee hearings, but also from the reports of increasing incidence of thyroid cancers among the Marshall Islanders who had been exposed to heavy fallout in the Bravo test in 1954. Thyroid nodules first appeared in 1963 among the eighty-six children under the age of ten who were exposed on the islands. Two additional cases were found in 1964, both in girls twelve to fourteen years of age. By 1975 twenty of these children with thyroid abnormalities had been exposed to thyroid doses of 175 rad or more, and seventeen of these to 810 rad or more. These disheartening reports made the thyroid studies in Utah even more important.

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In the autumn of 1963 the Division of Radiological Health began to assemble vital statistics and demographic data that would indicate morbidity and mortality rates for a number of diseases potentially related to radiation exposure. Some work was done in determining the frequency of selected thyroid diseases in Utah and Nevada, and some clinical examinations of thyroid nodules were made in children in one Utah county. In November a field investigator began collecting clinical-pathology case histories on Nevada and Utah patients with thyroid disease who were hospitalized and had surgery on the thyroid gland in the years after 1948.

The major thyroid study was launched in the fall of 1965 when two teams of six physicians and dentists began examining thyroid glands, teeth, and eyes in two thousand school children in the sixth through the twelfth grades in Washington County, Utah, where St. George was located. For control purposes fourteen hundred similar children were examined in Safford, Arizona. Each school child was examined independently by three physicians, and only those children with definite or suspected signs of abnormality were selected for further study. Indications of thyroid nodules were found in about seventy of the Utah students and twenty-five of the Arizona children. The Public Health Service then convened a panel of nationally known medical authorities on the thyroid gland to conduct further examinations of all children with definite or suspected abnormalities. During the years 1965 to 1968, 86 percent of all children in grades six through twelve were examined; in 1969 through 1971, only high school seniors. Of the 4,831 children examined during the first three years, 1,378 had been born or had resided during infancy and early childhood in the fallout area. An additional 1,313 moved into the area after most of the testing was completed, and these

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children served as a control group. The second population of 2,140 children in Arizona also provided a control.

The panel found no significant difference in any type of thyroid disease between the exposed group and the control groups. Of the 5,179 children surveyed, thyroid abnormalities were found in 201. The most common disorders were adolescent goiter, hyperthyroidism, and lymphocytic thyroiditis. Twenty benign tumors and two cancers of the thyroid were found, both in the control groups. One could postulate from the Utah and Rongelap studies that the Utah children had not ingested enough iodine 131 to cause a significant number of thyroid abnormalities. It was also possible, however, that the sample was too small, or the period of follow-up too short, to detect an effect.

While the thyroid studies were proceeding, epidemiologists and physicians in federal and state health agencies were conducting surveys of "space-time clusters" of leukemia, including three in Utah, in the search for common causes. None of these was directed at radiation per se, and none identified a common etiologic agent.

EMERGING THEORIES OF RADIATION INJURY

The interpretation of data was influenced not only by field studies but also by the evolving theory of the mechanisms of radiation injury. In 1972, both the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), appointed by the National Academy of Sciences, completed broad surveys of what was then known about the effects on populations of exposure to low levels of ionizing radiation. In the decade

following World War II, the genetic risks to the population had been the major factor in determining maximum permissible doses. According to the BEIR Committee, the general principles operating in 1972 were "(1) Mutations, spontaneous or induced, are usually harmful. (2) Any dose of radiation, however small, that reaches the reproductive cells entails some genetic risk. (3) The number of mutations produced is proportional to the dose, so that a linear extrapolation from high dose data provides a valid estimate of the low-dose effects. (4) The effect is independent of the rate at which the radiation is delivered and of the spacing between exposures." Experiments with mice in the 1960's proved the fourth assumption erroneous, thus further complicating the estimate of genetic effects.

By 1972 there was general agreement that somatic as well as genetic risks had to be taken into consideration, but genetic effects were still considered important. On the encouraging side, there had been a revolution in the science of genetics as the chemical structure of the gene and the nature of the mutation process came to be studied in great detail. Chromosome aberration was found to be an important cause of human malformation and embryonic death, and there appeared to be an association between radiation exposure and the production of chromosomal aberrations. Even with this new information, however, scientists were unable to make precise estimates of genetic risks, principally because there was almost a complete absence of information on radiation-induced mutations in man and no way to quantify the relation between an increased mutation rate and deleterious effects on human well-being. The BEIR Committee concluded: "Our knowledge is, therefore, insufficient to provide a strong theoretical basis for extrapolation from one biological system to another, and to man in particular. Nevertheless,

in the absence of accurate human data we have no choice but to rely mainly on information from experimental animals."

Despite the mountain of data collected since World War II, neither UNSCEAR nor the BEIR Committee in 1972 found a way of estimating with confidence the somatic effects of low-level exposure to radiation. Although there was universal agreement that radiation could cause cancer in large doses (above 50 rem) and at high dose rates (above 1 rem per minute), except possibly for fetal X-rays, there was little radiobiological or clinical evidence that low levels of radiation produced this effect. Numerical estimates at low levels required extrapolation from the risks detected at higher exposures. The BEIR Committee noted that the task of determining the induction of cancer by radiation was complicated by a number of facts: "(1) the cancers induced by radiation are indistinguishable individually from those occurring naturally, and hence their existence can be inferred only in terms of an excess above the natural incidence; (2) the natural incidence of cancer varies over several orders of magnitude, depending on the type and rate of the neoplastic growth, age, sex, and other factors; (3) cancer of any one type occurs in sufficiently low incidence in man that few irradiated populations are large enough to provide convincing quantitative data on the incidence of tumors of any one type or site; (4) the time lapse between irradiation and the appearance of a clinically detectable neoplasm is characteristically long, i.e., years or even decades." A further complication cited by the committee was the wide variation in relative biological effectiveness among different types of ionizing radiation.

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Although the BEIR Committee in 1972 did not accept the concept of a threshold below which low doses of radiation had no permanent biological effect, it was, in fact, far from satisfied with linear extrapolation to determine effects at low doses. The committee concluded, however, that "since there is no means at present of determining the values of the dose-effect slope in the low-dose region of interest, use of the linear extrapolation from data obtained at high doses and dose rates may be justified on pragmatic grounds as a basis for risk estimation."

RECENT STUDIES OF BIOLOGICAL EFFECTS

During the 1950's, scientists had conducted many studies of the biological effects of radiation. These research projects drew on data accumulated following the widespread use of X-ray therapy on persons with spinal disease in Britain and on data collected by the Atomic Bomb Casualty Commission on survivors of the Hiroshima and Nagasaki bombings. The increasing number of studies in the 1960's and 1970's also included occupational exposures (of radium-dial painters, radiologists, miners, nuclear industry workers, and military personnel), medical exposures associated with diagnosis and therapy, and environmental exposures resulting from residence in areas of high natural background.

In an effort to summarize this flood of new data, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 1977 produced a major review of the literature. This report, entitled Sources and Effects of Ionizing Radiation, stressed the difficulties inherent in estimating the risk of cancer from low-level radiation. In a new report in 1980, the BEIR Committee analyzed alternative ways of estimating the

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risk from low doses of sparsely ionizing radiation such as X-rays. The committee based its estimates on several different models and expressed some preference for the "linear-quadratic" model, in which the effect depends upon both the dose and the square of that value. At low-dose levels the committee's linear-quadratic estimates were about half those obtained with the linear model, in which the effect was calculated to be directly proportional to dose. In the absence of a firmly established theory of how radiation might cause cancer, the committee noted that the choice among alternative dose-response models remained somewhat arbitrary. Some choice was necessary, however, if low-dose estimates were to be derived from available data, which provided adequately stable estimates only for intermediate- and high-dose levels. The committee also concluded that the risks of cancer from low doses of sparsely ionizing radiation were too small to be observed directly.

Several of the new studies in the 1970's were based on efforts to determine low-dose effects directly. The BEIR Committee in 1980 dismissed these studies as inadequate in one way or another, but they remained controversial because they suggested that the risk of cancer might be very much higher than the estimates recognized by UNSCEAR and the BEIR Committee.

Perhaps the most controversial of these studies was that published by Thomas F. Mancuso of the University of Pittsburgh in 1977. Mancuso and his associates, Alice Stewart and George Kneale, examined death certificate data for 3,520 former workers at the atomic energy production plant in Hanford, Washington, who died during the years 1944-1972. By noting the cause of death, the Mancuso team was able to count the number of deaths from cancer. By examining radiation exposure records for these same persons,

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the Mancuso team concluded by statistical analysis that "men who eventually developed fatal cancers had been more often and more intensively exposed to external radiation than men with other causes of death." Other scientists disputed both the methods of analysis and the conclusions of the Mancuso team, but the Mancuso study did much to arouse widespread public concern about the hazards of low-level radiation. In the midst of the controversy that developed over the study, Mancuso charged that the Energy Research and Development Administration, which had replaced the Atomic Energy Commission in 1975, had terminated his contract when the agency discovered that the results of the study would be unfavorable. Although subsequent investigation failed to substantiate Mancuso's charges, the case received extensive coverage in the press and led to charges by environmental groups that the government had tried to suppress evidence of the harmful effects of low-level radiation and to silence scientists who tried to publish such information.

Other studies probing the incidence of cancer in industrial workers subjected to chronic low-level radiation followed the Mancuso paper. In September 1977, Thomas Najarian, a physician and fellow in hematology at the Veterans Administration Hospital in Boston, examined a former worker at the Portsmouth Naval Shipyard in Maine who was suffering from hairy-cell leukemia. When the patient told the physician that many of his coworkers at the yard had died from cancer at relatively young ages, Najarian decided to investigate. Denied access to government data on individual workers and without any reduced information on exposures to radiation, Najarian, with the help of graduate students and others, assembled the names of 1,722 former workers at the shipyard from more than one hundred thousand death

certificates. He then tracked down the next-of-kin for 525 of these workers and tried to determine from interviews whether the workers might have been exposed to nuclear radiation. Among those identified as "nuclear workers" Najarian found 56 cancer deaths where 31.5 might have been expected. He suggested that chronic, low-dose occupational exposure to ionizing radiation might carry a much higher risk than had previously been thought. A later examination of data on film-badge readings from the yard showed that deceased nuclear workers were more likely to be correctly identified as such by their relatives if the cause of death was cancer than if death resulted from some other cause. Najarian's study, which was financed in part by the Boston Globe, was widely publicized in the press. In response to Najarian's findings, the Department of Energy announced that it would make a follow-up study of workers exposed to radiation in seven yards where nuclear ships were repaired or refueled. In 1978 the Congress directed the Department of Health, Education, and Welfare to conduct a study of radiation effects at the Portsmouth Naval Shipyard, and Secretary Califano assigned responsibility for the study to the National Institute of Occupational Safety and Health within the Center for Disease Control.

An influential study of radiation effects of fallout was published by Joseph Lyon, an epidemiologist at the University of Utah, in 1979. Lyon and his colleagues directed their study to all cancers, but especially leukemia, in children under fifteen years of age in seventeen high-fallout counties in southern and eastern Utah. Lyon found that the childhood leukemia rate for the years 1959 to 1967 was almost triple that of the 1944-1950 period, which, however, was well below the average rate for the United States, Utah, and the low-fallout counties. In the years 1968-1975,

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the rate dropped to near the pretesting level. When the data were grouped, however, by year of birth rather than the year of death, the rate during the testing period was about double that of the earlier and later periods.

Although Lyon believed that he had found a very strong association between exposure to radioactive fallout and the incidence of childhood leukemia, he was careful to point out that, in the absence of precise data on the dose received by any single individual, it would be impossible to establish a cause-and-effect relationship for any specific leukemia deaths. Furthermore, he doubted that any such specific dose data would ever be found.

Scientists raised many questions about Lyon's results at the time. First, they found it significant, not that the leukemia rate for the high-exposure cohort in the high-fallout counties was high, but rather that the rate for the low-exposure cohort was abnormally low. Second, they noted that childhood cancers other than leukemia followed a pattern almost complimentary to that for leukemia, so that the sum for all cancers showed no relation to fallout levels at all. Third, the reviewers found that Lyon had not verified the length of residence of each child in the Utah area. Fourth, there had been no check on the accuracy of the diagnosis of leukemias and other childhood malignancies. In 1978 the Center for Disease Control approved a supplementary contract with the University of Utah to investigate these questions.

Another study, this time concerning former military personnel who had participated in troop maneuvers during the test series in the 1950's, began with a single medical examination. In November 1975 a physician in the Veterans Administration Hospital in Salt Lake City reported that a leukemia

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patient whom he had examined had taken part in the troop maneuvers at the Nevada test site. This report raised the possibility that radiation levels previously considered safe were actually causing cancer or that radiation exposure of the troops might have been greater than originally supposed.

To follow-up on this report, the Center for Disease Control set up a project to identify the military and civilian personnel who had participated in the military exercises. Early in 1977 the story of the Salt Lake City patient appeared in the news media, to be followed in June by an article in Parade magazine that resulted in more than two thousand telephone calls and letters from individuals who reportedly had participated in various tests since 1945. Among these was a letter from a second leukemia patient who had participated in the troop exercises at the Smoky shot during the Plumbob series in 1957. The Center for Disease Control then began to assemble data specifically on the Smoky test, which had produced some of the heaviest fallout within the test area of any of the troop participation shots.

By the end of 1977, the Center for Disease Control had found eight cases of leukemia among Smoky participants, but it was impossible to judge whether this number was unusual without knowing more about the total population. As in the Utah childhood leukemia studies, it was necessary to examine death certificates and to verify the diagnosis of leukemia. Unlike the Utah study, it was also necessary to determine the age structure of the military units at Smoky, since age would influence the expected cancer rate. By the summer of 1979, the Center had located 60 percent of the 3,244 former soldiers identified from film-badge records. Comparing the observed incidence with expectations based on national averages,

scientists concluded that the incidence of leukemia was greater than would have been expected. Unlike the Lyon study, the Smoky project did have the advantage of a rough indication of the amount of exposure from the film badges. This information brought the Smoky project somewhat closer than Lyon had been to relating exposure to the incidence of leukemia.

In the late 1970's scientists published new data on the Marshall Islanders exposed to heavy fallout during the 1954 tests. The thyroid nodules detected in Rongelap children in 1963 and 1964 proved the first of forty such cases diagnosed by 1976. The incidence of thyroid nodules was higher in children than in adults and positively related to dose in both groups. It also appeared that the smaller the dose, the longer it was before tumors became evident. As the incidence of tumors increased, the medical teams re-estimated the thyroid dose received as 335 rad for a Rongelap adult and 1,010 rad for a child under ten years of age. It was noted in this recalculation that the shorter lived isotopes of iodine delivered two to three times the dose received from I-131 alone. One mitigating consideration was the fact that the mortality rate for thyroid cancer was extremely low, about 0.0001 percent of the total population of the United States.

It seemed certain that additional thyroid problems would develop because, by 1974, about 50 percent of the exposed Rongelap people showed biochemical hypothyroidism without clinical evidence of thyroid disease. There was also an increased incidence of other types of cancer among the exposed population as compared with the unexposed group. Although these disorders were few and could not be ascribed definitely to radiation, one case of myelogenous leukemia was found in 1972 in a boy exposed to 175

rad when he was one year old. Based on the dose-response rate of leukemia determined from the Japanese experience and the low rate of spontaneous leukemia in the Marshallese, it was estimated that the chance that this leukemia was radiation-induced was five to fifteen times greater than the chance that it was spontaneous.

Recognizing the adverse health effects of the 1954 test, the United States government took steps to provide financial compensation for the Marshallese. In 1965 the United States made ex gratia payments of $950,000 to the Rongelap people. In 1979 a similar payment of $158,000 was given to the people of Utirik Atoll. Under legislation adopted by Congress in 1977, death benefits of $100,000 were made available to heirs of those Marshallese who died as a result of leukemia and other radiation-induced diseases.

NEW FEDERAL ACTION ON RADIATION STUDIES

Reports of these and other studies in the news media deepened public anxiety about the health hazards of radiation, not just in Utah and Nevada, but also in all parts of the nation. Telephone lines to the Departments of Defense and Energy were swamped in the fall of 1977 with calls from cancer patients, those who believed that they or members of their families had been exposed to radiation from nuclear tests, and from relatives of those who had already died. In response to this outpouring of anxiety and despair, the House Subcommittee on Health and the Environment held hearings to review "the extent to which the general public is exposed to radiation, the effects of radiation on human health, and to determine whether existing law is adequate to protect the public." The hearing resulted in a printed

transcript of more than 2,600 pages, which summarized the results of major studies to date.

In May 1978 President Carter directed the Secretary of Health, Education, and Welfare to formulate a program covering research on the effects of radiation exposure, the dissemination of information on what was being done, care and benefits for those adversely affected by radiation exposure, and steps that would reduce exposure. To carry out the directive, Secretary Joseph Califano established an Interagency Task Force on Ionizing Radiation composed of senior officials in the Departments of Defense, Energy, and Labor, the Veterans Administration, the Nuclear Regulatory Commission, and the Environmental Protection Agency in addition to his own Department. The Interagency Task Force set up six work groups which studied various aspects of the subject and published reports.

Additional support for federal research on radiation effects came from the Congress in 1978. Section 262 of Public Law 95-622 directed the Secretary of Health, Education, and Welfare to establish a comprehensive research program on the biological effects of low-level radiation and to undertake a government-wide review of federal programs in this field. The new law did not give the Department of Health, Education, and Welfare any control over the activities of other agencies, but it was intended to designate the Department as the lead agency in the federal government in research on the health aspects of radiation use. Operating responsibility for the new programs was delegated to the Director of the National Institutes of Health.

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The activities of the Interagency Task Force and the federal agencies themselves were closely followed by Governor Scott M. Matheson of Utah and members of the congressional delegations from Utah and Nevada. In November 1978, following a meeting with Governor Matheson and a visit to Utah, President Carter directed Secretary Califano to re-evaluate the findings of the earlier leukemia studies, such as those by Weiss and Lyon; to reopen the thyroid study in Utah, which had been terminated in 1971; and to consider expanding the Lyon study of childhood leukemias to include cancer studies in the larger population of Utah.

At the same time efforts were being made by both the federal and state governments to find and make available to the public all information related to radiation fallout and its effects within statutory limitations. In the spring of 1978 the staff of the Senate Subcommittee on Health and Scientific Research began reviewing classified and other previously restricted files held by the Departments of Defense; Energy; Health, Education, and Welfare; the Defense Nuclear Agency; and the Nuclear Regulatory Commission. Pertinent documents were declassified to the extent possible and released to the subcommittee. Early in 1979 Governor Matheson requested the same federal departments and agencies to release all information in their files related to fallout, long- and short-term health effects, and precautions taken during nuclear weapon tests since 1951. Governor Matheson also asked that all documents located and released during this search be placed in a central facility in the tri-state area, where they would be available to the public for research. By that time most of the federal agencies had already begun to seek out some of these records, many of which were released and discussed at joint hearings of the cognizant House and Senate committees

on April 19, 1979, in Salt Lake City and before the House Subcommittee on Oversight and Investigations in April, May, and August. Among the records printed in full in the transcripts were internal documents of the Atomic Energy Commission and its laboratories that revealed private discussions and correspondence about the fallout problem as it related to weapon testing.

Also released at the August hearing was a new analysis by Harold Knapp of the sheep deaths in 1953. Knapp attributed the high death rate of newborn lambs "to serious damage to their thyroids from doses in the range of 20,000 to 40,000 rad from the isotopes of radioiodine present in fallout from the 24 March 1953 test (Nancy), and ingested by the pregnant ewes 40-60 days prior to birth." There was little or no support for Knapp's conclusions within the scientific community.

CURRENT RESEARCH ACTIVITIES

Early in 1979 several federal agencies and departments responded to Governor Matheson's requests for assistance by organizing projects that would enable scientists to reconstruct and re-evaluate data related to the weapon tests in the 1950's. The Department of Health, Education, and Welfare continued to support research that might validate or refute the Lyon study and that would reopen the thyroid project terminated in 1971. The Department of Defense, with the Defense Nuclear Agency, has launched an extensive effort to find and re-examine film-badge data originally generated by military operations at the test site. Operational records are being used to determine more precisely which military units participated in each test and their movements during the post-shot period. Efforts are also being made to identify as many as possible of the individuals

who participated in each exercise. The Defense Nuclear Agency and the Department of Energy have arranged for the National Academy of Sciences to conduct an extensive health experience survey of a large sample of military personnel who took part in the Nevada and Pacific tests.

Because a very large proportion of the records concerning test operations had been inherited by the Department of Energy and its contractors along with the facilities of the Atomic Energy Commission, the Department started in 1978 to plan a comprehensive search for documents related in any way to off-site fallout. The Department's Nevada Operations Office identified more than thirty locations in which relevant materials were likely to be found. Documents selected in the screening process have been sent to Las Vegas, where they are being consolidated with related materials, indexed, and filed in a central facility operated by a Department of Energy contractor.

Most of the records being collected are technical in nature: logs and reports submitted by off-site monitoring teams, records of the thousands of film-badge readings and radiation measurements, and data on the specific isotopic content of fallout from each shot. The search, however, also encompasses a wide range of other materials, including internal correspondence, documents reflecting policy decisions about test operations, and administrative records setting forth procedures used in test operations, monitoring and safety activities, and public relations. The objective is to reconstruct a complete data base for each test shot that produced off-site fallout. All of these materials are being assembled at the new Coordination and Information Center, which will be ready for public use in Las Vegas in 1981.

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The data bases assembled for each shot are also being used by scientists from the Department of Energy's national laboratories, from laboratories operated by other federal and state agencies, and from universities to reconstruct accurate profiles of the fallout patterns and radiation exposures for each shot producing off-site fallout. The first step is to determine as precisely as possible the isotopic content of the fallout from each shot. This information is then used in re-evaluating off-site fallout distribution as functions of time and location. The next step is to construct a series of models of the various processes by which these isotopes moved from the test site to the human organism. Department officials hope that the data sets will provide large enough statistical populations to reduce or virtually eliminate the large probability of error inherent in the estimates of earlier studies. These stochastic models are being used to estimate external exposures and doses as functions of time and location, to simulate the pathway of fallout through food chains to humans, and to calculate organ-specific dose estimates resulting from inhalation and ingestion of fallout material. With these models the task groups hope to develop an integrated model which can be used to calculate the dose appropriate to a single individual's experience. Work on all phases of data collection and analysis had begun by the summer of 1980.

Over a period of three decades the Atomic Energy Commission, other federal and state health agencies, and private research institutions have spent tens of millions of dollars in exploring the biological effects of radioactive fallout. Hundreds of hours of testimony by experts have been presented in congressional hearings, which have resulted in tens of thousands of pages of printed materials. Hundreds of scientific papers on the

subject have been published in professional journals and subjected to rigorous review and criticism. Although convincing evidence has been accumulated to demonstrate that heavy exposure to radiation does cause cancer and other biological damage, competent scientists have still not been able to agree on the effects of chronic low-level radiation. A few studies have shown some correlation between low-level radiation exposure and the incidence of leukemia, but the statistical data so far available fail to establish a cause-and-effect relationship. One explanation is that the risks, however real, are too low to be reliably estimated in the available human populations.

The absence of conclusive data has generated in many Americans a gnawing fear and suspicion that fallout from nuclear weapon tests may have caused cancer, perhaps in themselves and members of their families. The toll of human suffering and death exacted by cancer makes the resolution of the fallout question not just a matter of scientific interest but also an issue of agonizing concern for thousands of people. The congressional hearings in 1978 and 1979 revealed this public anxiety. They also demonstrated a firm commitment within both the Executive and Legislative Branches of the federal government to pursue every avenue of research that might determine whether radiation from fallout did in fact cause the injuries and deaths which have occurred, to take steps to avoid such hazards in the future, and to provide equitable and compassionate compensation for those who may have suffered injury or personal loss. This commitment assures further investigation of the fallout question on a broad front. Whether these studies will produce definitive results remains to be seen.

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